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# Research on Remote and Hybrid Scientific Work

A Literature Review

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# Introduction

This literature review is divided into two parts. The first part looks at new developments and emerging research specifically related to remote work since the start of the COVID-19 pandemic. This encompasses research and reporting on the impacts of COVID-19 on the workplace, more speculative writing on the possible future of remote and hybrid work, and impacts of remote work during COVID-19 for diversity, equity, and inclusion. The second part focuses on more fundamental research done on remote collaboration and remote work tools prior to COVID-19, which addresses in more detail how different types, aspects, or stages of work can best be supported using virtual collaboration tools. In both sections, we review literature that directly focuses on remote scientific collaboration, which is somewhat limited, as well as the broader literature on remote and hybrid work, which is relevant to a wide variety of workplaces, including scientific ones.

## COVID-19 impacts and adaptation

Remote work and digital transformation were factors being considered by companies long before the pandemic hit. There are many benefits to remote work including the ability to collaborate with experts from around the world and taking advantage of time zones to have work going on constantly (Embrett et al., 2021; Gilson et al., 2021; Saatçi, et al., 2020; Standaert et al., 2021). Before the pandemic, in the US 5% of workers were remote out of the 30% of total workers that could successfully complete their tasks remotely (Phillips, 2020). Recent technological innovations such as email, videoconferencing, document sharing, AR and VR, have been changing workplace practices and have facilitated remote work and collaborations (Leonardi, 2021; Oyekan et al., 2017; Saarikko et al., 2020). This study explores the literature about remote collaborations and how their adoption, practices, and tools have been shaped by the pandemic.

The pandemic forced an immediate shift to remote work practices. Companies were left scrambling, but because of prior advances in technology and remote work practices, they were eventually able to adapt. Now, with access to vaccines and significantly lower case counts, companies are entering a period of transition into new work models based on the experience of the past year. This literature review will examine how organizations adapted to the pandemic, particularly those focused on scientific research, determine tools and strategies for remote work, and explore future work models and resources needed to facilitate them.

## Adapting to remote work

The pandemic had a large impact on the world; scientific researchers were not immune. There were two main types of papers encountered on the response of scientists to the pandemic: aggregate general surveys (Aczel et al., 2021; Gilmartin et al., 2021; Myers et al., 2020) and description and analysis of specific teams working on a project (Gravano et al., 2021; Sadeghi et al., 2021; Smite et al., 2021; Zaer et al., 2020).

In the first type, the papers cover the results of surveys of scientific researchers early in the pandemic (April to July 2020). A major finding in these three papers was that there was a decrease in productivity as scientists had to halt in person work and that scientists with children or working in certain fields (e.g., lab or field based) were most impacted. Additionally, Gilmartin et al. (2021) describes the challenges scientists faced with adopting remote communication methods, and Aczel et al. (2021) analyzes which research tasks are best completed at home or at work. There is a lack of papers reporting on the experiences of scientists later in the pandemic, likely due to the short period of time since then.

In the second type, a common theme was the use of new technologies for communication and collaboration. Smite et al. (2021) describes how software engineers adapted to do remote pair programming using platforms such as Tuple, "code with me extensions," and shared documents. To complete physical collaborative tasks that could not be done by videoconferencing alone, teams turned to telepresence (Zaer et al., 2020) and VR (Sadeghi et al., 2021) to allow for remote control of equipment and shared reference points. Gravano et al. (2021) describes how a biology laboratory altered practices for the pandemic, using virtual safety training and remote support for equipment. The literature contains examples from several different scientific fields and addresses multiple platforms for communication and collaboration. More research is needed regarding remote experimental collaboration and the different types of technology used, especially because of its potential to reduce travel costs and increase collaboration opportunities.

Remote work did not allow for face to face collaboration, so many teams had to learn new ways of communicating. The main synchronous communication method for most teams in the literature was videoconferencing; a list of different videoconferencing platforms is provided in Gravano et al. (2021). As described in Zaer et al. (2020) and Sadeghi et al. (2021), telepresence and VR were also used for synchronous collaboration, but these methods were less prominent in the literature. Asynchronous communication was achieved by a variety of platforms including shared documents (e.g., Google Drive), instant messaging (e.g., Slack), and email (Embrett et al., 2021; Whillans et al., 2021). Of importance in many of these papers is selecting an appropriate communication method based on the task. Standaert et al. (2021) evaluates different meeting methods, such as face to face and audio only, and provides a framework for selecting the most appropriate type based on the goal of the meeting. Several papers address more broadly how different synchronous and asynchronous communication methods support completion of various tasks (Embrett et al., 2021, Grozinger et al., 2020; Kozlowski et al., 2021; Whillans et al., 2021).

In addition to technological adjustments, remote work also forced teams to learn new practices and management methods. Some papers provided advice specifically for managers and leaders of virtual teams noting the importance of setting up norms for communication and providing opportunities for socializing and building relationships (Klonek & Parker, 2021; Kozlowski et al., 2021). Other papers drew on existing knowledge of teamwork and adapted the advice for virtual teams (Gilson et al., 2021; Whillans et al., 2021). Another set of papers focused specifically on

conducting virtual meetings with advice provided for running them in general in Kreamer et al. (2021) and special considerations for virtual meetings with an international collaboration component presented in Jarvenpaa and Keating (2021). The skills developed during the pandemic work from home experience are relevant for any future work model because of the increasing prominence of virtual teams and remote scientific collaboration (Embrett et al., 2020; Lee & Haupt, 2021).

## The future workplace

The widespread adoption of remote work during the pandemic has changed employers and employee's perspectives on remote work. The future of work will be different because of experiences during the pandemic. As noted in Phillips (2020) and de Lucas Ancillo et al. (2020), many companies are exploring hybrid work models to take advantage of the benefits of face to face and remote work. Employees too are seeking more remote work options in the future after experiencing the benefits of no commute and reduced workplace distractions (Parry et al., 2021). Focusing on scientists, Aczel et al. (2021) explores the trend towards remote work and suggests optimizing a hybrid model so certain tasks are done at home versus at work to increase productivity. There is a dearth of papers providing robust, detailed predictions or descriptions of future work models, likely due to the speed at which the pandemic situation is evolving. However, many non peer reviewed sources such as business blogs and newspaper articles discuss speculations and advice regarding hybrid work models, yet many note the uncertainty going forward (Gratton, 2020, 2021; Kelly, 2021; Pozen et al., 2021).

The logistics of hybrid work models have yet to be entirely determined, but already there is some discussion about future workplace layout and hybrid meeting practices. Hou et al. (2021) provides a description of changes in workplace layout for bringing back workers early in the pandemic with extensive safety protocol emphasized. In contrast, recent business blogs suggest that future workplaces will feature flexible use of space for collaborations with less regard for pandemic precautions given vaccine availability (Kane et al., 2021; Link, 2021). Hybrid meetings present unique challenges compared to remote meetings due to the likelihood that remote participants are not included fully. Based on observations of a hybrid meeting pre-pandemic, Saatçi, et al. (2021) analyzes actions that include and exclude remote participants in a hybrid meeting in a search for equal participation opportunities. Rosset et al. (2021) presents a technological solution, binaural audio, to help remote participants locate and identify the in-person speaker. In a business blog post, Frisch and Greene (2021) provide advice to make hybrid meetings a productive experience for both remote and in-person participants. More research in both of these areas is needed as people return to work and try new office designs and meeting formats in order to develop concrete recommendations for optimal hybrid work practices.

The pandemic accelerated the trends towards remote work and digitalization, leaving a lasting impact on workplaces. The sudden shift to remote work forced many businesses to adapt quickly, requiring investment in technological infrastructure and knowledge of digital communication and collaboration tools. Much uncertainty remains about future work models, but

research studies and media reports suggest that jobs are more likely to emphasize flexibility, digital capabilities, and the value of collaboration and relationships after the pandemic. Much literature is available on the early impacts of the pandemic on scientists and on strategies for remote teamwork and meetings. Less literature is available on future work plans and hybrid work models, but there are some non peer reviewed sources with information on these topics. Key areas for continued research include the longer term impacts of remote work on scientists and strategies for hybrid work models. As the next phase of the pandemic unfolds, we may be able to learn from prior remote and hybrid work experiences and to pay attention for insights from new work models.

## Diversity and inclusion

Several studies conducted during the pandemic looked at the impact of remote work on diversity, inclusivity, and accessibility. Having remote or hybrid work options does have the potential to advance diversity in some ways, particularly by enabling greater geographic diversity in hiring and allowing for more hiring flexibility for two-career families. However, it is not clear that the overall impact of remote work on diversity has necessarily been positive. One major issue is that many organizations concentrated on the immediate challenges of remote work and were no longer focusing on diversity and inclusion in the workplace (Dolan et al., 2020). Another example relevant to LANL is that students and early career employees faced fewer opportunities and diminished research experiences—especially those who could not do virtual positions which, in turn, disproportionately impacted people from underrepresented groups (Carr et al., 2021). Other studies focused on women scientists with children, particularly those with children under 5 years of age, finding that their research time diminished during remote work and they were offered fewer professional opportunities and/or less important assignments, which ultimately may have long-term impacts on their careers (Russell & Frachtenberg, 2021).

Accessibility for people with disabilities has also been impacted by remote work. Many people with mobility issues have benefited from not having to travel to work or their offices. Meetings via phone and videoconferencing became increasingly common and allowed accessibility in the home environment rather than relying on access features of conference rooms and buildings (Russell & Frachtenberg, 2021). However, the spectrum of ability differences in the workspace is very broad, and remote work has had negative as well as positive impacts. For example, the executive director of the New Mexico Commission for the Deaf and Hard of Hearing noted that many workers with these conditions have been very frustrated with lack of technological investment and employer support for their needs (Davies, 2021). We did not investigate these aspects of remote work in detail in a LANL context.

## Prior research on remote and hybrid work

The challenges and opportunities posed by remote and hybrid work were subjects of extensive research long before COVID-19 made them a topic of widespread concern. This research first

took off in the 1990s as it started to become clear that the Internet and telecommunications technologies had the potential to transform many aspects of society, including the workplace. Much of this early research, which peaked in the early 2000s, centered around the design and testing of noncommercial, experimental communication platforms. Despite some of this research being over 20 years old, much of it is still highly relevant because it was concerned with elucidating the fundamental parameters of different types of work and identifying how they could be effectively supported (or not) in a remote work context. While workplaces have certainly changed in the interim, current research still draws on many of the fundamental characteristics identified in this earlier work. The wide variety of remote work tools now available in some ways complicates the ability to do this kind of fundamental research and may draw attention away from these fundamental behavioral parameters. Figure 1 shows relationships between key factors shaping remote and hybrid work practices in the sciences.

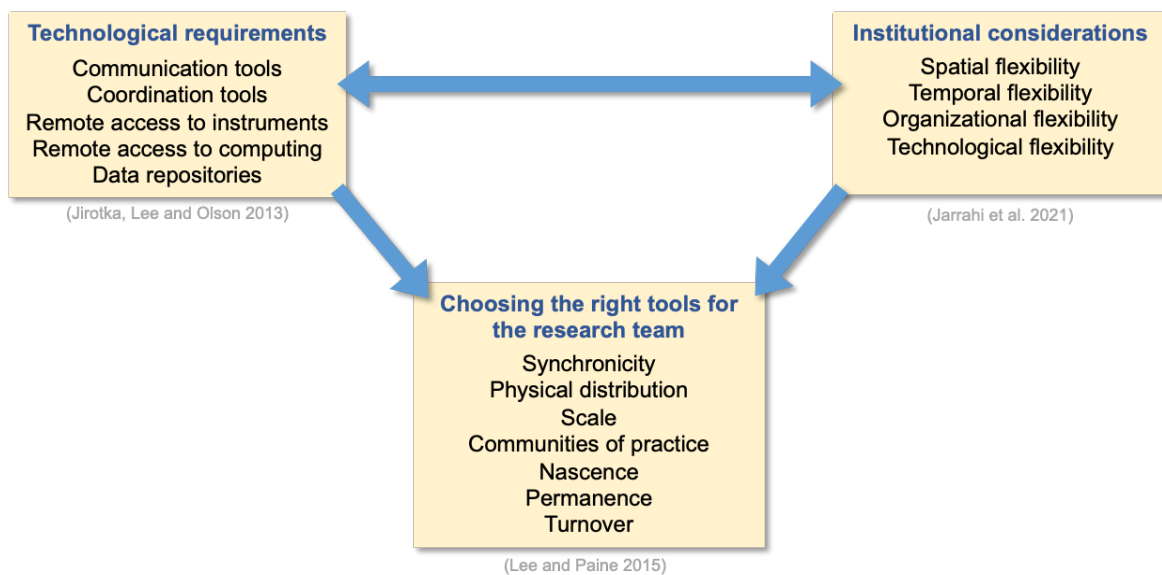


Figure 1. Relationships between key factors identified in the literature on remote and hybrid scientific work

Research on the specific needs of remote scientific work has been done under a number of research programs and topics, including e-Science, e-Research, Grid Science, Cyberinfrastructure (a term used by the U.S. National Science Foundation), Virtual Research Environments (VREs) and Collaboratories (Jirotko et al., 2013). Because these research areas originated before the widespread availability of remote work tools, much of the research focused on understanding general scientific needs and building broad infrastructures or platforms for collaborative scientific work. In general, it also emphasized remote collaboration between physically distant research groups, rather than remote work within a single team or institution, which is our focus here. For this reason, in this review we concentrate on research at the teams or group level that is relevant to the scientific context, even if it is not specifically focused on science. Despite its limitations for our purposes, this scientific infrastructure-oriented literature does provide some useful categories for understanding remote work tools. For example, Jirotko

et al. (2013) describe the required classes of tool functionality for collaboratories as follows (emphasis and bullets added):

- “*Communication tools* which allowed the participants to communicate either in real time or asynchronously”
- “*Instrument access* allowing remote access to instruments that were key to the domain ...”
- “*Computation* providing access to high end computational resources ...”
- “*Repositories* that allowed groups to create and access stores of data, publications, and other materials ...”
- “*Coordination facilities* such as calendars, providing awareness information, and in general facilitating the coordination among members of these projects”

These categories still appear to be highly relevant to the needs of LANL scientists we spoke to.

## Computer-supported cooperative work

To better understand the remote collaboration needs of research projects, teams, and groups within an institution like LANL, we focus on the field known as Computer-Supported Cooperative Work (CSCW). This field started as a small subset of research on human-computer interaction (HCI), but has since expanded into a major specialty in its own right, associated with multiple journals and conferences. As its name suggests, CSCW is largely concerned with developing and evaluating tools that enable groups of people to work together, as opposed to HCI's more typical focus on individual interactions with information systems. As such, CSCW largely operates at the intersection of computer science and the social sciences. We focus on this field because of its emphasis on how the day-to-day dynamics of work - including scientific and technical work - can be supported and transformed by new technologies. We divide this portion of our literature review into two major topics: choosing the right medium for the work and opportunities and overheads.

*Choosing the right medium for the work* covers much of the fundamental research in the key parameters of remote and hybrid work described above. The key issues here are the physical distribution of workers (whether they are all in one place, clustered in several places, or completely remote from each other) and the temporal coordination of their work (whether they need to work simultaneously on shared tasks, or can contribute to tasks at different points in time). Different kinds of work are easier or harder to do under specific conditions of physical and temporal distribution of work. This depends on factors like common ground (whether people need to work closely with a shared set of objects and assumptions), presence (how much the work relies on nonverbal cues or other subtleties of interpersonal interaction that are difficult to transmit at a distance) and the need for informal interactions, which happen less easily in remote work situations. Overall, we note the importance of learning and adaptation in this literature: that is, successful use of remote and hybrid work tools depends not only on translating existing workflows into virtual environments, but also evolving to create new work arrangements that can make the most effective use of new technologies.

*Opportunities and overheads* focuses less on specific tasks and more on how people manage the increased flexibility allowed by remote or hybrid work to create viable workplaces for individuals and work groups. Key parameters to be managed include:

- Spatial flexibility (where people can work)
- Temporal flexibility (when people can work)
- Organizational flexibility (what work arrangements or roles people can have)
- Technological flexibility (what tools and technologies workers can use)

For each of these, there are trade-offs between the benefits and costs of allowing greater flexibility. In addition to categories like telework, remote work, and hybrid work, this research addresses the possibility of mobile or nomadic work, where individual workers are not necessarily tied to any specific work location, on- or off-site, an option that is appealing to many workers. These work arrangements all create potential challenges for organizations, particularly in establishing a sense of place and belonging for workers and teams that do not share a traditional office space.

## Choosing the right medium for the work

If hybrid work involves a mix of on-site and remote work, then the question which immediately arises is what work should be reserved for on-site collaborative situations and what can be done remotely. In many organizations, hybrid work will likely not be a simple division between off-site and on-site situations of work, but rather will involve a variety of different tools and platforms for collaborating, from email and instant messaging applications like Slack to video and audio conferencing to task management systems. On top of this, people often use collaborative technologies even when they are working together at the same location. The range of collaborative situations that hybrid work entails is therefore highly heterogeneous. Research starting in the 1990s, when technologies for video or audio-based remote work were entering many workplaces, approached this question by investigating different media to understand what kinds of interactions they are able to support, and what their limitations might be (Olson & Olson, 2000; Jirotko et al., 2013). The strengths and limitations of different technologies depend not only on the nature of the work itself, but also parameters related to collaboration, such as size or rate of turnover of the working group.

To understand how hybrid or remote work can be accomplished, then, we need to characterize the different parameters of collaborative work in some way. CSCW researchers have developed a variety of frameworks for describing collaborations, ranging from the straightforward to the somewhat complex. The Model of Coordinative Action (Lee & Paine, 2015) is an example of the former. It provides a concise set of dimensions along which situations of collaboration might vary (Figure 2). These include measurable features such as physical distribution, synchronicity, scale, turnover, and number of communities of practice. Other dimensions may be harder to characterize, such as nascence or planned permanence, which have to do with the maturity and potential duration of the collaboration.

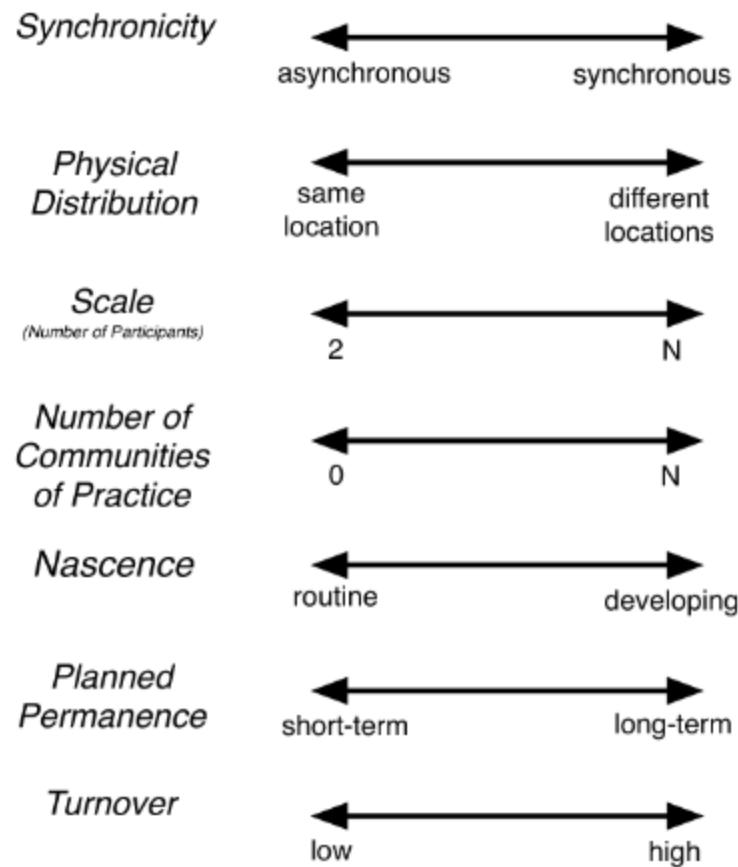


Figure 2. Dimensions of the Model of Coordinative Action

We use this framework to organize our discussion of how different media can support particular aspects of collaborative work. First, we discuss two key elements of the model, physical distribution and synchronicity. Then we examine the other elements under a set of broader themes that connect them to different bodies of work in CSCW: common ground, formality, learning and adaptation, and interdisciplinarity and diversity.

## Physical distribution

Physical distance is obviously very important in the context of remote collaboration, but its role is not entirely straightforward. Most notably, Olson and Olson (2000) attempt to dispel the idea, prominent in studies of collaboration in the early 2000s, that problems of distance can be completely nullified by emerging collaborative technologies. They summarize a great deal of research from the 1990s and outline 10 characteristics of in-person (co-located, synchronous) interaction that are more problematic in remote interactions, including rapid feedback, implicit cues, ease of establishing joint reference to objects, and informal “hall time” before and after meetings. They further observe that certain kinds of “closely coupled” interactions are particularly hard to transfer to remote collaborative technologies. This includes highly ambiguous kinds of work, such as planning or creative tasks. Cummings and Kiesler (2008)

note that projects involving multiple institutions often use events like periodic in-person workshops in order to overcome difficulties inherent in remote work. Under this model, the groups hold just a few in-person working events per year where they accomplish tasks that require close collaboration.

This approach is framed to a large degree around the idea that in-person interaction is the gold standard for collaboration, and other media for interaction are “impoverished” in comparison. Scholars studying collaboratories and virtual organizations in the early 2000s drew on a large amount of prior research demonstrating that non-verbal signals (such as gestures) can improve information communication and turn taking in collaborative tasks (Boyle, et al., 1994), and that visual channels can be used to disambiguate unclear audio communication (Krauss and Bricker, 1967; Veinott et al., 1999). Much of this work draws on media richness theory and the idea that media such as in-person interaction and videoconferencing are “richer” than other kinds of communication (Fish et al., 1992). Even videoconferencing, however, does not provide the same quality of interaction as meeting in person, and using any kind of remote communication channel requires some overhead in terms of adapting to the constraints of the tool. This includes trying to identify who is speaking, addressing audio and visual technical breakdowns, and miscommunication due to poor audio or visual connection (Olson and Olson, 1995; Isaacs and Tang, 1994, Heath and Luff, 1991).

Similar findings emerge in other studies of distributed work. Hinds and Bailey (2003), for instance, describe how conflict emerges more readily in distributed teams due to miscommunications prompted by asynchronous interactions. Information transfer in general is more difficult in distributed teams (Cramton, 2001; Hinds & Weisband, 2003). Zolin et al. (2004) observe the importance of trust in distributed, cross functional teams, and demonstrate that factors such as cultural difference can have a negative impact on the ability of groups to establish trust. They further observe that the initial establishment of trust is critical in such situations.

Despite the focus on the importance of in-person interaction in this literature, some researchers have noted that in-person interaction is not always the most desirable option. As Nardi and Whittaker (2002) point out, it can be expensive to bring people together, and exhausting to interact in person. Moreover, early experiments with group collaboration suggested that audio-only (Hindus & Schmandt, 1992; Yankelovich et al., 1995; Ackerman et al., 1997) or text chat interactions (Nardi et al., 2000) could be promising alternatives.

## Synchronicity

Synchronous collaboration is work that one or more people engage in at the same time, whether they are together or working remotely from each other, while in asynchronous collaboration people may contribute at different times. For many groups, an increase in remote working may lead to more work being done asynchronously, while at the same time increasing the need for tools that enable remote synchronous collaboration.

Synchronous work generally allows people to coordinate their interactions much more closely around specific work objects. Early studies of synchronous work in a shared text editor demonstrate that having mutual access to a document allows people to reference different parts of the text and coordinate and delegate work on those different parts (Dourish and Bellotti, 1992). More recent work by Wang, A. Y. et al. (2019) has examined similar benefits to collaborative editing of computational notebooks, finding that synchronous work (rather than working independently) provides a shared context and reduces communication costs. At the same time, synchronous work requires what Wang et al. describe as strategic coordination, and can result in redundant work and unbalanced participation if this is not done well. Furthermore, in certain circumstances a person may want to work separately, either to try something themselves or so that their work is not scrutinized while in progress (see also Rule et al., 2018).

Working asynchronously, on the other hand, introduces problems of disconnects in who is working on what and what progress has been made where. Studies of computational notebooks describe the “mess” that develops when different versions of code or output are left behind during coding work, a problem which can lead to researchers being reluctant to share notebooks with others (Kery et al., 2018). Even when shared, it can be difficult for a newcomer (or the same researcher later on) to make sense of what work was done, particularly around ephemeral pieces of context, such as the deliberations that led to certain decisions or approaches that were tried and discarded. This has led to work suggesting that documentation and histories can be an important way of facilitating understanding across asynchronous activities in computational notebooks (Kery & Myers 2018; Wang et al., 2021).

Outside of studies of computational notebooks, documentation, histories, or other kinds of traces have been a central focus of studies of asynchronous computer-supported work. This includes research on providing tools for annotation and commentary on text documents (Cadiz et al., 2000; Weng & Gennari, 2004), as well as more general observations about the use of traces for coordinating work across work sessions. For instance, Mosconi et al. (2017) describe how a neighborhood community coordinates the asynchronous work of watering a garden through a simple paper notice board. A key idea here is accountability, where documentation and activity traces are used to capture task assignments or contributions, allowing for better work coordination as well as tracking of work responsibilities and assigning credit for work completed. These technologies often supplement older accountability methods, such as keeping meeting notes or minutes.

## Common ground

While much of the research in the early 2000s on remote collaboration was influenced by media richness theory, Olson and Olson (2000) also develop the notion of common ground from Clark (1996). Common ground refers to the sense of familiarity and shared understanding among collaborators, specifically the knowledge that collaborators have in common, and are *aware* they have in common. Elements of common ground can include things like shared language, shared understanding of local events or places, and disciplinary knowledge.

However, common ground is not just based on a backdrop of prior knowledge, but is also constructed through cues in interaction. For example, collaborators may revise what they think they have in common when they identify and correct misunderstandings in a conversation (Clark and Brennan, 1991). Gestures and other cues, as well as a shared set of reference objects, can reduce the potential for miscommunication. These elements of common ground may be easier to establish in videoconferencing media in contrast to audio-only or text-only messaging, or if a shared document or whiteboard is available. Overall, it is easiest to establish common ground in face-to-face meetings, but much more difficult in media such as audio-only conferencing, where it is difficult to establish who is speaking, what object or document somebody is referring to, and so on.

The notion of common ground emphasizes the importance of visual communication, but there are also other ways of establishing common ground that are not dependent on visuals. For example, in an experimental setup involving a simple puzzle workspace, Kraut et al., (2002) showed that audio and a shared visual of the puzzle could reduce queries between collaborators and improve performance on a given task. Dourish and Bellotti (1992) show a similar process by which collaborators establish shared referents in a collaborative text editing workspace. Birnholtz et al. (2005) demonstrate the value of a simple chat function for establishing common ground in certain circumstances. In particular, they show that a chat environment allowed a large, distributed group of researchers to stay up to date on the current step of an ongoing experiment, and also provided a way of bringing newcomers up to speed. A chat function was sufficient to establish some common ground in this particular collaboration because it had low information and low clarification needs, so a low-investment chat channel was a useful tool. Findings from this research area, then, suggest that there can be very good reasons to make use of chat or audio-based communication channels to establish common ground, despite the fact that they do not support a richer set of gestural cues and expressions.

## Presence

Common ground is closely related to the notion of presence. In the simplest sense, presence is the ability to determine who is present in a given interaction and identify different parties as they contribute. The most familiar form of presence is our participation in face-to-face interaction, sometimes referred to as “co-presence.” Clark and Brennan (1991) identify the following characteristics of co-present working environments:

- Visibility—visible to each other.
- Audibility—speech.
- Contemporality—message received immediately.
- Simultaneity—both speakers can send and receive.
- Sequentiality—turns cannot get out of sequence.
- Reviewability—able to review other’s messages.
- Revisability—can revise messages before they are sent.

In virtual situations, it may be more difficult to establish these aspects of presence, leading people to adapt in various ways. As mentioned above, identifying oneself verbally is a practice

that has developed in audio-only interactions (Ackerman et al., 1997), but it also happens in videoconferencing sessions with a large number of people (Sonnenwald et al., 2003). However, a strong sense of presence is not always desirable. One of the benefits that Nardi and Whittaker (2002) identify about an instant messaging system, for instance, is the “plausible deniability” of one’s presence: the ability to pretend that one is not there to respond to a message, which can be productive in certain circumstances.

## Informal interactions

One recurring concern in the literature on remote work, running from the early 1990s through the most recent literature, is how to facilitate informal interactions in a remote work setting. Most generally, informal interaction is any communication which does not follow the hierarchy or structure of an organizational chart but rather cuts across those structures (Monge et al., 1985), and may be described using terms like watercooler talk or “hall time” (Olson & Olson, 2000). Researchers have identified informal communication as critical to a variety of organizational functions, such as building relationships and learning organizational culture. Studies have shown that informal communication is easiest when people are working in physical proximity to each other (Kraut, et al., 1988) and able to communicate face-to-face (Bly, et al., 1993).

The goal of facilitating informal interaction has been a persistent concern of designers and researchers of remote collaborative technologies (Stray & Moe, 2020; Nardi & Whittaker, 2002; Whittaker, et al., 1994; Fish et al., 1992). Fish et al. (1992) find that videoconferencing technologies do not maintain all of the benefits of in-person interaction for informal interaction; participants in their study found impromptu video calls invasive and tended to use them for organizing further meetings or reporting on status, rather than decision making or problem solving. When there is a need to organize video calls in advance, this further inhibits the possibility of facilitating impromptu meetings (Dourish et al., 1996).

More recent efforts have worked with other ways of facilitating informal interactions. Stray and Moe (2020), for instance, experimented with the use of a persistent video feed in order to prompt ad hoc interactions between two distributed software teams. While initially successful, the feed was eventually abandoned due to decline in use, and the teams ultimately relied primarily on Slack for such interactions. The use of messaging apps like Slack has been the focus of another prominent stream of research on informal interaction (Mao et al., 2019; Wang et al., 2019). Nardi et al. (2000), for example, argue that the deniability of presence that messaging apps allow is part of what enables them to effectively support informal interaction. Others have noted the importance of auditory interactions for creating a *peripheral awareness* between collaborators in a workspace (Heath and Luff, 1992).

## Learning and adaptation

The fit of a given technology for a specific kind of work is not just a matter of its fit with currently established practice, because groups often adapt their work practices to new technologies to make full use of them. This learning process can mitigate some of the negative impacts of remote collaboration, and even enable innovation as people develop new approaches to

interaction that leverage specific features of new communication tools. Dourish et al. (1996) take as a starting point the idea that a set of communicative practices tailored to a specific medium develop over time. This was the case in Sonnenwald et al.'s (2002) study of a large research collaboration, in which researchers adapted to the use of videoconferencing applications by developing new practices, such as identifying themselves and their locations when speaking. Similar behaviors were described in Ackermann et al. (1997). They argue that although the audio-only medium they studied had non-trivial drawbacks in comparison with video, participants adapted their practices to make the technology work, and to take most advantage of its benefits.

On the other hand, the literature also relates situations in which the activities of researchers or collaborators simply did not adapt to a newly adopted technology, often resulting in disuse. In addition to the persistent video feed described in Stray and Moe (2020), Olson et al., (1998, 2008) describe the implementation of a web interface for viewing real time data in an upper atmosphere and space physics collaboration. They found that researchers, in general, did not adapt their practices to the new interface, and for a large part of the collaboration it fell into disuse. This may be related to what Olson and Olson (2000) describe as “technological readiness,” which in this case refers to the readiness of the collaborating parties to learn and adapt to a newly introduced technology. This is not just an aspect of individuals’ attitude towards the technology, but also dynamics of the group as a whole. Orlikowski (1993), for instance, examines the failure of a firm to adopt the Lotus Notes technology due to a mismatch between the tool and the company’s focus on rewarding unique contributions rather than contributions to a shared knowledge base. This readiness may also have strong cultural or generational elements depending on the technologies that are most familiar to a given group.

## Interdisciplinarity and diversity

While the dimensions of physical distribution and synchronicity are fairly straightforward, other aspects that have come under study in CSCW, such as cultural or disciplinary differences, are harder to characterize. While Olson and Olson (2000) identify interdisciplinarity as one of the things that can contribute to difficulties in communication (and a lack of common ground) in collaborative groups, much of the research on interdisciplinary collaboration has focused on a higher institutional or organizational level that is not as relevant to our focus on collaborative teamwork (Welsh, Jirotko and Gavaghan 2006, Cummings and Kiesler 2008, Ribes and Bowker 2008). This suggests that the problems posed by interdisciplinarity might be at a more general level where whether a team is working in person or remotely may not be quite so relevant.

Findings from investigations of language and culture bear more closely on interaction and interpersonal collaboration. Zolin et al. (2004) point out that remote work, by enabling more physically distributed collaborations, may also allow for an increase in cultural diversity on teams. Other research has shown (e.g., Brewer 1996; Luo, 2007) that trust is easier to establish among people of similar cultures and harder to establish between people of different cultures, in this case referring to people of different national backgrounds. Veinott et al. (1999) observe that the importance of video is increased for collaborators who do not share a language. In particular they point to the use of gestures to clarify concepts for which participants do not have a shared

vocabulary. Williams (1997) supports this, demonstrating significant differences in use of video and audio communication channels among people who speak different languages.

## Opportunities and Overheads of Hybrid Work

Another area of research relevant to hybrid work is the study of mobile, nomadic, and flexible work. This literature encompasses older studies of remote work as well as more recent research on emerging nomadic and flexible remote working arrangements, particularly in emerging industries such as the gig economy, as well amongst “digital nomads” who have taken advantage of new technologies to travel while working. Although this kind of roaming may not be typical of hybrid work, research on this topic has developed important insights about the value of place and how people configure individual and shared workspaces under a variety of circumstances. These insights have immediate relevance for hybrid workers.

Jarrahi et al. (2021) provide a useful framework for understanding the various kinds of flexibility that researchers have identified in relation to flexible and nomadic work (Table 1). This framework allows us to capture one consistent finding which is relevant to this report, which is that technologically-enabled flexibility in working arrangements comes with both opportunities and overhead costs in the form of new requirements for managing and coordinating work under such flexible arrangements. Both workers and organizations face these trade-offs. In the following discussion, we discuss the categories from Table B under the cross-cutting headings of enabling mobility and place-making.

<b>Dimension of Flexibility</b>	<b>Definition</b>	<b>Examples of supporting digital technologies</b>	<b>Examples of technological constraints</b>
<i>Spatial flexibility</i>	The extent to which workers can detach themselves from specific locations and workspaces	Portable computational equipment Non geo-restricted access to systems Adequately reliable and affordable Internet connectivity Access to charging stations and/or long battery life	Fixed computational equipment Geo-restricted access to systems Lack of access to reliable or affordable Internet connectivity Lack of access to charging stations and/or low battery life
<i>Temporal flexibility</i>	The extent to which workers can detach themselves from specific work schedules	Complex time and task management systems Personal cloud services (e.g., Google drive) Asynchronous communication platforms and norms	Blurring of work-life boundaries Digital distractions Inflexible time and task management systems
<i>Organizational flexibility</i>	The extent to which workers can detach themselves from organizations' administrative control	Digital labor platform Bespoke employment/engagement contract. Digital accounting mechanisms Community-developed add-ons and plug-ins (e.g., scripts)	Policies restricting the external use of enterprise systems Technical management norms
<i>Technological flexibility</i>	The extent to which workers can self-curate the infrastructure that supports their work	Ownership of personal IT (e.g., personal devices and cloud); Systems that operate across platforms and devices	Lack of interoperability of enterprise applications/task management software/file formats

Table 1. Dimensions of flexibility in remote and nomadic work (Adapted from Jarrahi et al., 2021)

## Enabling mobility

One important source of empirical findings on spatial flexibility comes from research in the early 2000s on teleworking or homeworking. The work-at-home movement of the early 2000s was distinguished from previous kinds of home work by the widespread use of digital technologies to support connections between workers and the office, although this was not necessarily a sharp distinction (Huws, 1997). As Dix and Beale (1996) point out, much of this early research assumes that although workers are remote, they have stable, fixed sites of work. Teleworking was largely framed as working from home, and motivated by the possibility of avoiding or reducing commuting (Sullivan, 2003). The instances of teleworking researchers actually studied did entail working from a variety of different places (Baruch, 2000; Lamond, Standen, and Daniels, 1998), but in the long run studies of teleworking shifted away from a focus on a notion of *home* working, and towards a notion of *remote* working, which examines the problems and opportunities of working remotely from potentially multiple locations. This has, in turn, prompted a larger turn towards mobility and a focus on movement between work sites in the sociology of work (Hislop and Axtell, 2007). However, in the wake of the COVID-19 pandemic, there has been renewed interest in the home as a particular place for work, especially in relation to the tensions that arise between work and home life (Ciolfi, Gray, and de Carvalho, 2020).

Mobile work is a slightly different concept than remote work or telework. Although they both assume the use of digital technologies as a way of supporting new kinds of access to the work resources, mobile work is focused on the tasks implied in moving from place to place during work. This can include moving from one in-person work site to another in order to have face-to-face communication with different people (Bellotti and Bly, 1996; Lamming et al., 2000). This difference makes research on mobile work extremely relevant to planning for hybrid work, because hybrid work may involve not only remote work, but also the ability to work flexibly across multiple sites (such as home, a shared office, and drop-in work spaces). In a study of mobile workers, Perry et al. (2001) identify four challenges that characterize mobile work, which include:

- Planning (in particular planning for unexpected situations and work environments)
- Making use of dead time (or travel time)
- Accessing remote technological or informational resources
- Monitoring the activities of remote colleagues.

In addition to mobility, there has been significant work on the related concept of nomadicity, in which workers may not be tied to any specific location. As Ciolfi and de Carvalho (2014) put it, nomadicity “...involves both the movement of people and things but also the work in preparing for such movement and following the movement in creating conditions to engage with work and life activities” (pg. 121). In order to work in this way, a worker must be able to flexibly configure required resources at multiple locations, such as privacy, time, quiet, and access to electricity and Wi-Fi. In order to move between different spaces, they must also spend time navigating gaps and seams between infrastructural resources at different locations (Vertesi, 2014; Jarrahi and Sawyer, 2017).

## Place-making

A persistent concern of the research on mobile and nomadic work is the tradeoff between the benefits of increased flexibility and the extra work that is required to manage that flexibility. Mazmanian et al. (2013) discuss an “autonomy paradox”, observing that adoption of mobile devices may increase workers’ sense of autonomy, while at the same time creating a norm of anywhere/anytime connectivity that ends up reducing their autonomy in practice. Studies have found that teleworking has benefits for workers, such as increased organizational commitment and job satisfaction, but also resulted in a perceived intensification of work and the inability to “switch off” outside of formal work hours (Felstead and Henseke, 2017). Among “digital nomads”, who conduct remote work while traveling, the tension between getting work done and relaxing or enjoying their travels (which was the whole point of adopting such a lifestyle) is a central difficulty that requires planning and self-discipline to maintain (Cook, 2020; Sutherland and Jarrahi, 2017).

Studies of mobility and nomadcity have paid particular attention to place as an important and persistent concern for mobile workers. Different locations afford different activities and ways of interacting with others, and take on meaning as identifiable *places* through human interaction (Brown and O’Hara, 2003). One way of describing this is that mobile work does not simply “take place” but rather “makes place” (Ciolfi, Bartolucci, and Murphy, 2005). What this means is that workers must establish the different locations where they are to accomplish their work as work places, which requires planning, know-how, and the use of technology. It is not only a matter of finding resources in different places, but planning work to be accomplished in different places which afford different resources, such as quiet or internet access. Sutherland and Jarrahi (2017) found that different workspaces had very different meaning for traveling workers, such that some said they could accomplish certain kinds of creative work in trains but not elsewhere. Part of the benefit of the work on nomadcity, then, is that it demonstrates that “location independence” is not something that is simply granted by technology, but rather is something that itself requires a great deal of work. While working nomadically may imply a freedom from dependence on place, it also entails taking on more work to establish different places as viable work settings (Nash, Jarrahi, and Sutherland, 2021).

One way issues of place become particularly relevant for hybrid work is in the need to coordinate work both within multiple places (both on and off site) and across those locations through virtual interactions (Cabitza et al., 2016). Mosconi et al. (2017) describe the coordination of in-person events and discussions in a neighborhood community with discussions occurring on a social media site. The issue of coordinating digital infrastructures and information resources with work occurring on site, including through analog media, has been a long-standing issue in the sciences, where design projects such as ButterflyNet attempted to reconcile the digital catalogs and spreadsheets of researchers with the pen-and-paper notes they take in the field. Such studies highlight the fact that certain kinds of hybrid work have been present in scientific research for a long time prior to the exigencies surrounding COVID-19.

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